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ARMY MEDICAL RESEARCH LABORATORY

FORT KNOX, KENTUCKY

REPORT NO. 225
7 March 1956

COMBINED ENVIRONMENTAL STRESSES AND MANUAL DEXTERITY

*Subtask under Psychophysiological Studies, AMRL Project No. 6-95-20-001, Subtask, Climatic Effects on Psychophysiological Abilities.

RESEARCH AND DEVELOPMENT DIVISION
OFFICE OF THE SURGEON GENERAL
DEPARTMENT OF THE ARMY

REPORT NO. 225

From Project No. 6-95-20-001

COMBINED ENVIRONMENTAL STRESSES AND MANUAL DEXTERITY

by

Edwin G. Aiken

from

Psychology Department

Submitted

7 December 1955

18 pp & ii 3 illus.

Abstract;

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ABSTRACT

COMBINED ENVIRONMENTAL STRESSES AND MANUAL DEXTERITY

OBJECT

Much of the field maintenance work performed by Army personnel is done under conditions of environmental stress. The sources of these stresses are varied and the precise tasks numerous. The purpose of this research was to develop a task representative of the field maintenance problem and then investigate the effects of 3 stress sources on efficiency at this task.

RESULTS

A test-retest reliability measure indicated that the task used was a highly reliable measure of mechanical dexterity. Mechanical dexterity was significantly depressed by stresses of low temperature, intense sound and low illumination. The effects of temperature and noise stresses on kinesthetic judgment (muscular control) were significant and appeared to be cumulative; while low illumination had no apparent influence on kinesthetic judgment and the detrimental effects remained constant.

CONCLUSIONS

A reliable measure of motor skills can be obtained with a task which closely simulates line maintenance conditions. A number of representative environmental stresses act to depress both speed and accuracy. Length of exposure, as well as intensity, is an important determinant of behavior changes under stress.

RECOMMENDATIONS

That provisions be made for systematically relieving workers who are exposed to stresses such as extremes of noise, temperature and illumination.

Research should be extended on combined stresses to include more extensive sampling of stress values and less gross measurements of stress effects. Attempts should be made to develop means for alleviating "generalized" stress reactions.

Submitted 7 December 1953 by:

Edwin G. Aiken, 1st Lt, MSC

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COMBINED ENVIRONMENTAL STRESSES AND MANUAL DEXTERITY

I. INTRODUCTION

The sources of physical discomfort to the line maintenance worker are numerous. When extreme, these stresses interfere with efficient performance of the maintenance tasks. It is important to know something about the characteristics of the reactions that can be expected to these stresses, particularly in the combinations most frequently encountered. Questions of stress interaction and cumulation arise in this regard. Actually very little, if any, data are to be found on the effect of combined stresses on the types of motor skills that are typically used in maintenance.

The literature pertaining to the effects of environmental stresses upon human motor behavior has been contributed largely by those who are interested in the effects of climatic factors (1 through 16). Ambient cold and heat act directly on the hands of the human operator and should be expected, therefore, to bear a close relationship to manual performance and dexterity. Low temperatures almost universally act to reduce efficiency, provided the measures are sensitive enough and the temperature departures extreme. The high temperature range data are less clear cut.

There is little doubt that some sort of psychological stress reaction accompanies the effect of direct cold upon the hands and body and this generalized internal discomfort is here postulated to arise from any extreme form of environmental stimulation. If it is reasonable to assume that at least part of the effect of cold stress comes from internal stress reactions that are independent of its direct influence upon hand movement dexterity, then by submitting a subject to stresses not directly related to the performance, a test for the existence of a generalized internal stress effect can be made. For example, there is no direct physical relationship between the effect of high noise exposure and manual dexterity, so that if an effect is shown it must be attributed to some internal debilitating stress reaction. Likewise, if the illumination provided over a work area is reduced to an amount that will permit adequate visual discriminations, but low enough to be annoying, another source of general internal stress not directly related to the performance task is created. The additional use of the temperature variable in a single experimental setting would permit a rough comparison of these generalized stress inducers with a stress source directly related to motor efficiency. The present experiment was designed to shed light on these issues.

II. EXPERIMENTAL

A. Subjects

Forty male army personnel from a variety of Fort Knox units, including a few personnel from this laboratory, were used as subjects. Due to the very fundamental character of the task, no major selection criteria were required. Subjects were assigned randomly to the 8 experimental conditions.

B. Apparatus and Methods

Training and post-test sessions took place in a room that was connected to the air-conditioning and heating plant, lighted by overhead flourescent bulbs and free of unnecessary noise. It made a suitable stress-free, "neutral" environment. Test sessions took place in the experimental cold room.

The task is one involving a variety of motor skills ranging from gross muscular behavior to fine kinesthetic adjustments. At the first training trial, the subject was given a general picture of the purpose of the study, shown the tools available to him and told to go through the task step by step with the help of the examiner. He was assured that the first trial was a demonstration only and that no timing was involved.

The task began with the removal of the 4 cotter pins which had been run through the large bolts on the top plate. A pair of long-nosed pliers was supplied for this purpose. Next, the 4 large and 4 medium sized bolts were removed with a large crescent wrench and the top cover lifted off. Because the large bolts were welded to the under side of the plate it was unnecessary to grip them from below in order to remove the nuts.

The next part of the task (Fig 1) involved removing the middle plate. The 4 medium sized and smaller nuts and bolts were removed by raising the trap door at the middle of the plate and reaching under to hold the bolt while turning the nuts with the smaller crescent wrench. Removal of the middle plate exposed the floor plate. A total of 7 numbered tasks confronted the subject at this point. First, the small metal covering plate in the middle of the base plate was taken away by removing the 4 screws with the Phillips screwdriver provided. This exposed to the subject a metal rule with 2 marks on it. The task was to pull the spring-mounted pointers to the point where each was above one of the markings and fix them there with a set screw and nut. Next, the subject had to make a micrometer measurement at the tips of 2 posts. He was not required to read his own setting. He simply set the micrometer and passed it to the experimenter who recorded the setting. Next, the subject turned a knob through a prescribed arc and attempted to set it at a point which bi-sected that arc. The mechanical construction of one of these knobs is shown in Figure 1. There were 2 other micrometer measurements and 2 other arc bi-sections facing the subject on the base plate before the first phase of the task was completed. The micrometer tasks and arc bi-sections were employed to bring tactual and kinesthetic processes, respectively, into the situation. In all there were 3 micrometer settings - narrow, medium and wide and 3 arc bi-sections - 50°, 100° and 200°. The order in which these tasks were to be done was shown in the numbering on the base plate beside each task.

It should be noted that although the micrometer measurements were retained throughout the experiment, the tendency of subjects to collide with them while working at the task kept them out of a constant adjustment so that the data from them was not used in the analysis. However, the fundamental idea behind this task seems to be a good one and it will be used in subsequent work, but with protective guards around the posts to prevent the problems that arose here. By employing highly uniform knob structures and painting the base plate the same color as the knobs, the use of visual cues for successive settings of the knobs was made impractical, so that muscular sensations had to be relied upon. This data was retained.

The re-assembly of the equipment was quite straightforward. The subject removed the set screws from the spring-mounted pointers, pushed them aside and replaced the small covering plate over the scale. He then replaced the 8 nuts and bolts, holding the middle shelf in position, wired the trap door closed, and then replaced the 8 nuts on the top shelf, putting new cotter pins in place. The presence of an experimenter during all trials assured that nut replacement met the criterion of finger tightness. This completed the total task.

Very few restrictions were placed on the manner in which the subject went about the task. The structure of the apparatus and the available tools made the mode of attack from subject to subject highly similar.

Before the test sessions began for a subject, his auditory threshold for the tank noise was obtained by attenuating the signal 100 db and adjusting the sound intensity at the pre-amplifier controls to the point where it was just perceived by the subject. Then by removing specified amounts of noise attenuation, it was possible to deliver tank engine noises at known amounts above threshold. The 2 intensities used in this investigation were 80 and 100 db above threshold.

C. Experimental Design

Because one of the research interests in this study concerned the combined and interactive effects of different stress types, an analysis of variance was considered the best design for the problem. In terms of test conditions, there were 8 Experimental groups--3 variables, each varied in 2 ways. This produced a 2 x 2 x 2 design as shown in Table 1.

For any particular stress or interaction comparison, a total of 40 subjects was available, 20 in each group.

The post-test trial in the neutral environment produced a measure of the effect of the test trials on learning and a reference score for comparing performance in various stress conditions with performance in a neutral environment.

III. RESULTS AND DISCUSSION

To determine the reliability of the measuring instrument, a Pearson correlation coefficient was computed between the total task time on the second and third trials of the test. The reliability coefficient was thus of the test-retest type and yielded a value of +.97. This is exceedingly high and it may be concluded that the measuring task used had a high overall reliability.

Some indication that the various experimental conditions were matched was needed. This information was obtained by means of an overall analysis of variance of these data. The average total time for the 3 training trials was chosen as the most representative score for this purpose. The findings of this analysis are shown in Tables 2 and 3.

The F ratio is lacking in significance. This establishes the initial performance equality of the various groups prior to testing, so that any differences which may arise under the experimental conditions of the test trials can be attributed to the stress variables and not to any sort of sampling bias.

The most representative score, average total time during the test trials, was used for the basic analysis of the variables. Tables 4 and 5 present the results.

The effect of the stresses upon performance is shown in the analysis. The temperature, noise and illumination stresses all acted to reduce performance in a very significant degree when considered individually. There were no significant interactions, however, which is to say that the individual stresses acted independently of one another in affecting the manual dexterity of the subjects.

Having established the existence of rather strong effects on the speed of motor behavior from 3 different sources of environmental stress, a question arose as to whether these variables would also show an effect on the accuracy of the responses. The experimental set-up permitted 2 measures of motor accuracy. One was in terms of the micrometer measurements and the other the dial bi-sections. As mentioned previously, interference with the placement of the micrometer posts made reliable measurements at those points impossible. However, the dial bi-sections worked quite well. Since visual cues in this task were reduced to a minimum, the settings were taken to reflect kinesthetically guided motor accuracy. For the purpose of analysis, the 3 settings of the 3 dials during the training trials were compared with the 3 settings of the 3 dials during the test conditions. This comprised 9 measurements per subject under each of the 2 conditions. As a measure of dial setting reliability, the range of the 9 settings during the 3 training trials versus the range of the 9 settings during the test trials was employed. The precise tests used were chi squares. The number of subjects in the high and in the low stress conditions on each variable were compared as to the number in each group showing an increase in variability from training period to test period. A separate chi square was run for each of the experimental variables with the result shown in Tables 6, 7 and 8.

From these data it is clear that the level of task illumination did not influence the reliability of the dial settings. This isn't amazing considering the fact that the dial setting task rested on kinesthetic and not visual information. However, the chi square values for both the noise and temperature variables are significant, so that an effect from experimental variations of these 2 variables on this skill is indicated. The exact interpretation of these effects is ambiguous, since the significant chi square values resulted not only from the decreased reliability under the high stress levels, but also from the increased reliability under the low stress levels. It is at least a plausible hypothesis that the low stress levels of noise and temperature had no effect upon this kinesthetic skill. The decreased variability is probably attributable to an improved performance with practice. The decreased reliability of dial setting under high noise and temperature stress could be interpreted as arising from a decremental influence which was sufficiently great to impede the natural course of improvement with practice and produce instead a decreased reliability of dial setting during the test trials.

A further analysis of the effect of the stresses on performance variability was made in terms of the time scores. For this purpose variability in the total time on the third test trial was compared with the variability in the total time for the post-test. This involved a difference test between scores made by the same subjects so a test for the difference between correlated standard deviations was made. Only the subjects in the highest stress level on each variable were used for the separate tests so as to maximize any difference found. The results are shown in Table 9.

These results may be interpreted as indicating that all 3 sources of stress, after a sufficient period of time, serve to increase the variability in subject speed. Individual differences in manual dexterity thus may be relatively unimportant if the task attempted is a simple one performed under relaxed conditions. If, however, stressful situations are anticipated, selection must be done more carefully, since any differences can be expected to become exaggerated as the spread of performance increases.

The question arises as to the relationship between speed and accuracy on this task. For this purpose, a Pearson coefficient was computed between the range of dial settings and the average total time on the test trials. The obtained r was +.273 which with 38 degrees of freedom (d.f.) produced a P value slightly short of the .05 level. Thus, there is a low but stable relationship between the speed and accuracy of performance. The relatively low value obtained is most likely attributable to the slight tendency for very slow subjects to make more careful adjustments and for very speedy subjects to carry their set for speed over to the accuracy tasks. In any event, individual prediction from speed to accuracy of performance under stress is poor.

The total performance curve is of some interest in indicating the character of the task used. Figure 2 shows a plot of the average total time scores for all groups on the 7 breakdowns and re-assemblies of the equipment. Trials 1, 2 and 3 were training trials; 4, 5 and 6 the test trials, and trial 7 the post-test. It is apparent that the first 3 trials show an almost linear increase in skill at this task. The next 3 trials show another linear decline in total time required, but not at as great a rate. The fact that the post-test score is only slightly lower than the third training trial implies that a good deal of the decline in total task time during the test trials is attributable to an adaptation to the stressful conditions. It is likely that performance speed on this task is roughly at maximum by the fourth or fifth trial and almost surely so by the seventh trial. The observation of importance is that this task combined a representative degree of maintenance task simulation with a rapid learning rate--a good combination for a manual dexterity task.

One final analysis appeared to be of interest. It concerned the cumulative effect of the stresses. The problem of obtaining a meaningful measure of this effect was solved by means of a ratio score. Specifically, 5 time measurements were taken at various convenient points during the total dis-assembly--re-assembly sequence. By computing t ratios for correlated means for the difference between the third test trial time scores and the corresponding post-test measurements, it was possible to express the degree of difference between the test and post-test performance at a series of points throughout the task with an index which took into account the increasing variance at each of the points. To obtain meaningful points along the baseline for each of the arbitrary task points, the average elapse of time during the third trial to the point of each comparison was used. Three curves were plotted in this fashion, one for each of the maximum levels of the 3 stress variables. The graph obtained is shown in Figure 3.

Consider first the temperature stress curve, which shows the least ambiguous pattern. The 6 ratios rise steadily from the early part of the task to the end, indicating that the action of the temperature variable is cumulative. However, the slope of the curve is much less from the third point on than over the first 3 points, suggesting that an upper limit is being reached.

The noise stress curve is complicated by the inversion at the second measurement point. Otherwise, the cumulative-leveling effect seen in the temperature variable is repeated here. Whether the inversion is a significant one is unknown, but it might be interpreted as an immediate adaptation to the noise, which gives way later to the prolonged irritations and stresses of unescapable, high-level noise.

The illumination variable, it is interesting to note, shows a very high stress effect immediately and then falls off to a slightly lower level and remains relatively constant. This is understandable in terms of visual light adaptation between the first and second measurements. Apparently, little cumulative stress can be expected from reduced illumination of the level used here, though it will produce rather intense decrements at a constant level.

An examination of the probability levels of the various t's entering into these 3 curves shows that they do not reach the .05 level of confidence until the third point of measurement on the noise variable, while on the illumination and temperature variables they are in excess of this value throughout the task. The line at t = 2.093 indicates the .05 level for the graphed t values.

The significance of most of the data of this study has been discussed. One point, however, needs elaboration. This is the fact that sources of stress not physically relevant to manual dexterity were shown to affect its efficiency. This is the case with illumination stress to some degree, but is clearest with regard to the stress resulting from the tank engine noise. It would be reasonable to assume that sources of stress which directly affect the body surfaces of the subject will influence motor skills. Low temperature is an example of such a physically relevant source of stress. That this factor acts to decrease manual skills is not very surprising and, in fact, has frequently been empirically demonstrated to do so. However, continuous high-level noise, and to a lesser extent, moderately reduced illumination are not related to motor efficiency in any direct fashion. There are no clear reasons why they should be expected to influence dexterity. However, it is clear from the data presented here that their influences are relatively strong--illumination stress produced more decrements than the more physically relevant cold variable and noise stress approximated that of temperature. This implies that the effect of any environmental extreme is to produce an intervening stress state whose effect is sufficiently generalized to affect negatively a wide variety of behaviors. In fact, it appears that a useful distinction can be made between generalized and specific stress in all research of this type. All specific stresses apparently produce, in addition to specialized effects on certain sensory-motor systems, a more pervasive tension state which acts to produce an overall reduction in behavioral efficiency. The action of this generalized stress state can be equal or greater than the more focalized stress of directly relevant annoyances. This fact should be given greater attention by those investigating environmental stresses. It is possible that the major cause of inefficiency resides in generalized psychological tensions and that the means for alleviating these stresses are quite different from the means for alleviating the specialized influences of environmental pressures. A systematic study of the locus and extent of generalized tension states appears to be appropriate. It is at least a possibility that men may be able to withstand much higher levels of specific discomforts, if their generalized tension level is low.

IV. CONCLUSIONS

A reliable measure of motor skills can be obtained within a task which closely simulates line maintenance conditions.

A number of representative environmental stresses act to depress both the speed and accuracy of these skills.

Length of exposure, as well as intensity, are important determinants of behavior changes under stress.

V. RECOMMENDATIONS

When designing stress protection devices for line maintenance functions, it is necessary to consider sources of stress other than those most apparently involved in the work. In this investigation it was shown that the psychological stress arising from prolonged exposure to high level engine noise can act to produce impairment in gross mechanical skills. Thus, if high level noise exposure, poor illumination or cold exposure are unavoidable in such work, provision should be made for systematically relieving the workers. The necessity for such stress relief periods increases as exposure time mounts.

Research should be extended on combined stresses to include more extensive sampling of stress values and less gross measurements of stress effect, e.g. perceptual efficiency, vigilance, etc.

Attempts should be made to develop means for alleviating "generalized" stress reactions.

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TABLE 1

EXPERIMENTAL CONDITIONS USED DURING STRESS TRIALS

LOW TEMPERATURE				HIGH TEMPERATURE			
LOW ILLUMINATION		HIGH ILLUMINATION		LOW ILLUMINATION		HIGH ILLUMINATION	
LOW NOISE	HIGH NOISE	LOW NOISE	HIGH NOISE	LOW NOISE	HIGH NOISE	LOW NOISE	HIGH NOISE

TABLE 2

AVERAGE TOTAL TIMES DURING TRAINING CONDITIONS

GROUP			AVERAGE TOTAL TIME
TEMPERATURE STRESS	NOISE STRESS	ILLUMINATION STRESS	
High	High	High	14.88 min
High	High	Low	15.08 "
High	Low	High	14.12 "
High	Low	Low	13.60 "
Low	High	High	15.87 "
Low	High	Low	12.84 "
Low	Low	High	12.64 "
Low	Low	Low	15.72 "

TABLE 3

ANALYSIS OF VARIANCE OF THE AVERAGE TOTAL TIME DURING TRAINING FOR THE 8 EXPERIMENTAL CONDITIONS

Source of Variance	Sum of Squares	d.f.	Mean Square	F Ratio
Between Groups	54.23	7	7.75	1.07
Within Groups	230.83	32	7.71	
Total	285.06	39		

TABLE 4

AVERAGE TOTAL TIMES UNDER TEST CONDITIONS

GROUP			AVERAGE TOTAL TIME
TEMPERATURE STRESS	NOISE STRESS	ILLUMINATION STRESS	
High	High	High	21.78 min
High	High	Low	16.87 "
High	Low	High	17.87 "
High	Low	Low	13.27 "
Low	High	High	18.53 "
Low	High	Low	12.52 "
Low	Low	High	13.73 "
Low	Low	Low	12.78 "

TABLE 5

ANALYSIS OF VARIANCE OF THE AVERAGE TOTAL TIME DURING THE TEST TRIALS

Source of Variance	Sum of Squares	d.f.	Mean Square	F Ratio
Between Temperatures	93.51	1	93.51	9.64**
Between Noise Levels	90.60	1	90.60	9.34**
Between Illuminations	169.66	1	169.66	17.49**
Temperature x Noise	5.54	1	5.54	.57
Temperature x Illumination	3.61	1	3.61	.37
Noise x Illumination	17.93	1	17.93	1.85
Temperature x Noise x Illumination	14.56	1	14.56	1.50
Within Groups	310.38	32	9.70	
Total	705.79	39		

** .01 Point or better

TABLE 6

COMPARISON OF THE RANGES OF DIAL SETTING BETWEEN TRAINING AND TEST UNDER 2 TEMPERATURE LEVELS

	14° F.	41° F.	
Subjects Showing Increased Range	12 (9)*	6 (9)*	18
Subjects Showing Decreased Range	8 (11)*	14 (11)*	22
	20	20	40

$x^2 = 3.64$
d.f. = 1
$P < .01$

TABLE 7

COMPARISON OF THE RANGES OF DIAL SETTING BETWEEN TRAINING AND TEST UNDER 2 NOISE LEVELS

	100 db	80 db	
Subjects Showing Increased Range	14 (9)*	4 (9)*	18
Subjects Showing Decreased Range	6 (11)*	16 (11)*	22
	20	20	40

$x^2 = 10.2$
d.f. = 1
$P < .01$

* Numbers in parenthesis indicate the frequency expected from the marginal totals of the tables.

TABLE 8

COMPARISON OF THE RANGES OF DIAL SETTING BETWEEN TRAINING AND TEST UNDER 2 ILLUMINATION LEVELS

	High	Low	
Subjects Showing Increased Range	10 (9)*	8 (9)*	18
Subjects Showing Decreased Range	10 (11)*	12 (11)*	22
	20	20	40

$x^2 = .40$

d.f. = 1

P. = .54

* Numbers in parenthesis indicate the frequency expected from the marginal totals of the tables.

TABLE 9

COMPARISON OF THE TIME SCORE VARIABILITY BETWEEN THE THIRD TEST TRIAL AND POST-TEST

Temperature Stress	t = 2.24	P = .04
Noise Stress	t = 2.04	P = .06
Illumination Stress	t = 3.51	P = <.01

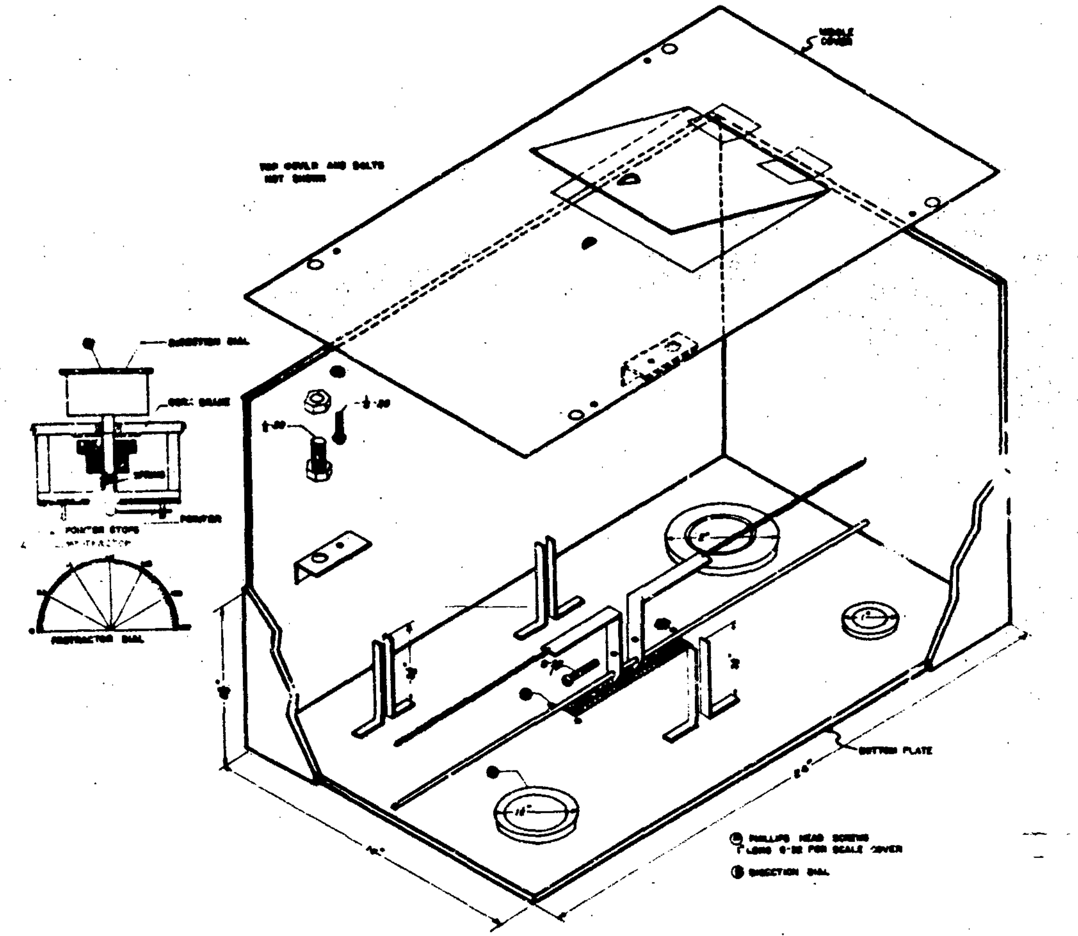

FIG. I INTERIOR OF APPARATUS FROM MIDDLE COVER DOWN

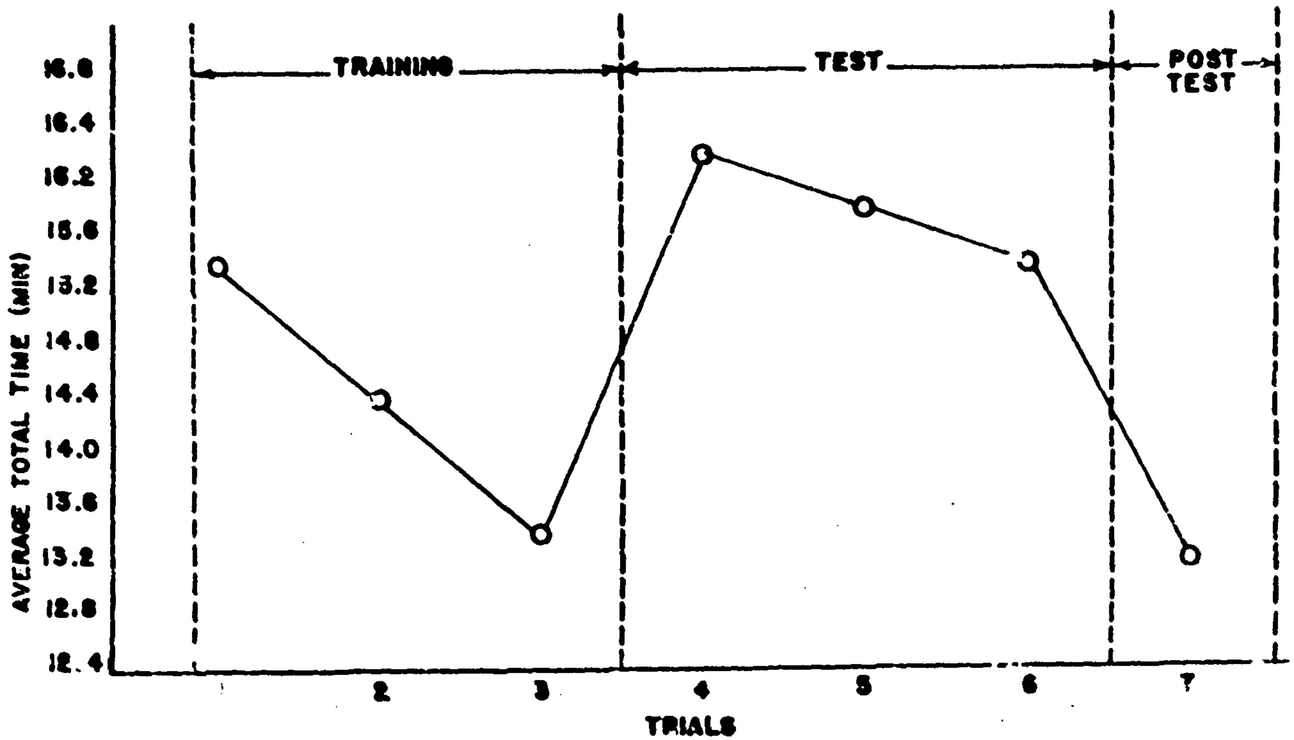

FIG. 2 PREFORMANCE CURVE FOR ALL SUBJECTS THROUGH THE SEVEN TRIALS ON THE APPARATUS

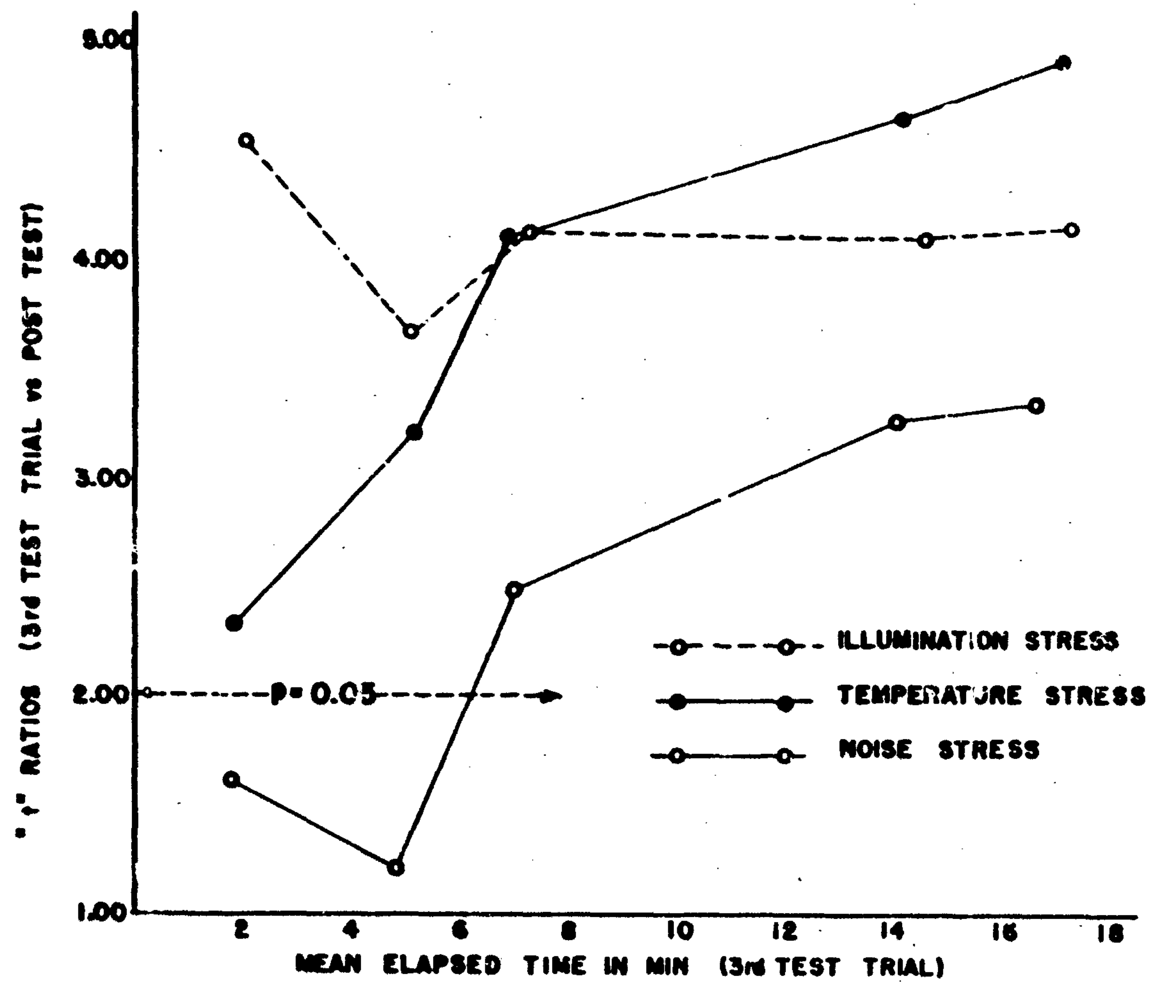

FIG. 3 DIFFERENCES BETWEEN THIRD TEST TRIAL AND POST-TEST (T-RATIOS) FOR THE HIGH STRESS CONDITIONS OF TEMPERATURE

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